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THE MOVEMENT OF SALMON (*SALMO SALAR*) THROUGH AN ESTUARY AND A FISH-PASS

By

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INTRODUCTION

Despite a considerable literature on the biology of the Atlantic salmon, reviewed by Pyefinch (1955), and Jones (1959), comprehensive data relating to the migratory movements of this species and factors influencing them is lacking. In this paper we have attempted to analyse in quantitative terms the behaviour of the salmon of the River Erne during the important phase of migration when the fish first enter brackish and fresh water. This investigation has been carried out at Cathaleen's Fall power station, one of two hydro-electric generating stations built (1945-1951) on the Lower River Erne by the Electricity Supply Board (Ireland). It is equipped with a fish-pass and is situated at the head of tidal water. A short description is given of automatic counters devised to record the upward passage of salmon through the fish-pass. In addition, we have had available data supplied by the Fisheries Division of the Department of Agriculture and Fisheries relating to the salmon fishery of the Erne estuary.

The Erne is predominantly a grilse river (Went, 1942; Twomey, 1959). Tagging experiments off the Donegal and Achill coasts (Went, 1951) and at Streedagh (Went and Gibson, 1953) indicate that the fish approach the mouth of the river both from the north and from the south. The incidence of fresh water spates, variations in temperature and variations in light intensity have all been alleged to influence the movement of salmon into an estuary or from an estuary into fresh water. Menzies (1931) has stated that grilse may remain in coastal waters for some considerable time, the principal cause being dry weather, and that they are attracted up a river by a spate, although they may concentrate at the mouth during the first days of the spate. However, Hayes (1953) states that natural and artificial spates will not by themselves induce a run of salmon into an estuary. Instead, he suggests that on-shore winds and increasing tides, i.e., those following neap tides, cause a concentration of salmon in an estuary. He also believes that the fish move out of tidal waters into fresh water at dusk, and he suggests that the stimulus for this movement may be the change in light intensity. In contrast to his observations relating to the behaviour of the fish when entering an estuary, Hayes believes that salmon may be induced to leave estuarine waters and to enter fresh water by artificial freshets or by sudden reductions in flow. According to Ward (1939) even a moderate rise in a stream as a result of rain may induce a run of Atlantic salmon and sockeye salmon although, when a stream is unusually swollen, the migration may be temporarily suspended.

Temperature variation appears to have little effect in initiating a run of salmon in a river or on the hourly rate of migration through a fish-pass (Hayes, 1953; and MacKinnon and Brett, 1953) although there may be threshold levels of temperature which inhibit salmon migration. Pyefinch (1955) states that a fish-pass can be an obstacle which will not be surmounted by salmon until the water temperature rises to 42°F, while Jones (1959) suggests that exceptionally high temperatures may also make such obstacles impassable.

With regard to the influence of light intensity, Ward (1939) has found that the upstream migration of sockeye salmon in a river is greatest in the morning and in the evening. On cloudy days, activity is intermittent during the middle of the day, but direct sunlight brings activity to a halt both in a river (Ward, 1939) and in a fish-pass (Jones, 1959). Experiments on the passage of steelhead trout (*Salmo gairdneri*) have shown that these fish are slower to enter a darkened fish-pass, but having entered, their passage through it is significantly more rapid than through the same fish-pass under conditions approximating to daylight (Long, 1959). Ward (1939) found that adult sockeye salmon cease their upstream migration in a river during the hours of darkness while MacKinnon and Brett (1953) show that coho and spring salmon will not enter the Stamp Falls fish-pass at night. They have been able to establish a relation between light intensity and the hourly rate of migration of salmon through the fish-pass and they found that the thirteen pools of the pass are empty of these fish at night.

THE ERNE ITS FISHERY AND FISH-PASS

The River Erne has been regarded as an important salmon river from remote times. For more than three centuries salmon were trapped at the Assaroe Falls which lay at the head of the Erne estuary (Went, 1945). The traps were removed in 1946 and the Assaroe Falls ceased to exist three years later as a result of the hydro-electric construction works. Cathaleen's Fall power station, which is built immediately below its associated dam, discharges water into the Erne estuary through a mile-long tailrace (Fig. 1) which for most of its length is cut 50 feet wide in rock. The power station tailwater is subject to tidal variations, but these diminish with increasing discharges from the turbines. The estuary of the Erne is $3\frac{1}{2}$ miles in length and opens westward into Donegal Bay. The fish-pass at Cathaleen's Fall is of the White submerged orifice type (Committee on Fish Passes, 1942) and is similar to those developed and used by the North of Scotland Hydro-Electric Board at their Pitlochry and Clunie power stations. The fish-pass extends over the dam into the reservoir (Fig. 1) and discharges its water into the tailrace close to one of the turbine draft-tube openings. The 112 feet gross head at the dam is taken up in the fish-pass by 73 pools. These pools are in general 24 feet long by 12 feet wide, the usual depth of water being 5—6 ft.

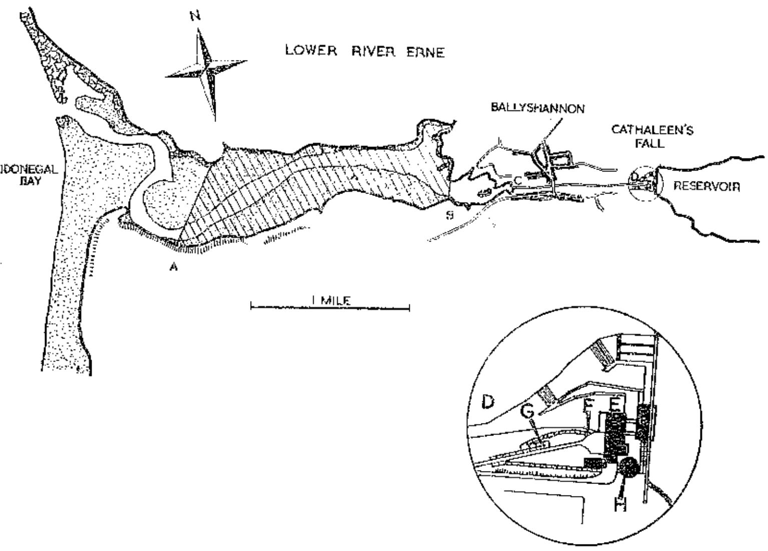

Fig. 1. The Lower Erne, from the sea to Cathaleen's Fall reservoir. The fishing zone (A—B); the tailrace (C—D). Inset: the power station (E); fish-pass pools 10 (F), 24 (G) and 58 (H).

Successive pools are connected at the bottoms of the cross-walls by 27 inch diameter orifices. The lowest pools, numbers 0 to 7, are under the station structure and are therefore shielded from direct daylight. Of these pools, five or six are submerged at high tide and when the turbines are operating at full load. For the greater part of its length the orientation of the fish-pass is East-West.

APPARATUS AND METHODS

One of us (P.A.J.) has constructed a simple fish-counter which consists basically of three parts :—

Inscales (Fig. 2)

Screen Unit (Fig. 3)

Numerical Register and/or Graphic Recorder.

The numerical register may be incorporated as part of the screen unit. The inscales which guide the fish to the counting device are in the form of a truncated pyramid 4 ft long, open at the 3 ft square base and at the 1 ft square truncated apex.

Each of the four sides consists of a grille of 2 inch by 1 inch timbers two inches apart. The truncated end which faces upstream is covered by the screen unit, while the base covers the upper end of an orifice in a cross-wall between two pools (Fig. 2). The

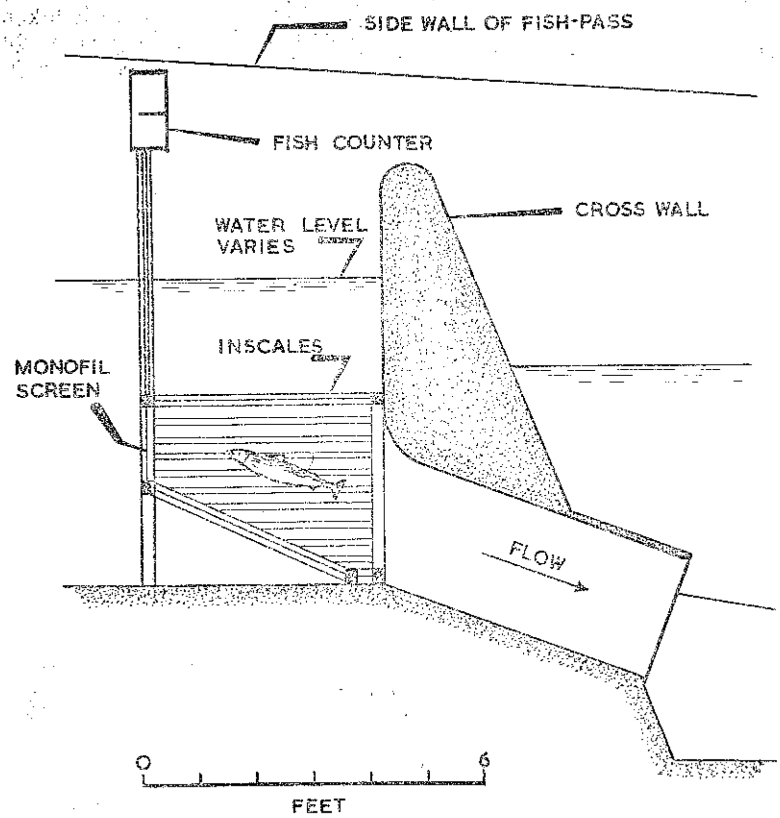

Fig. 2. A cross-wall in the fish-pass showing the siting and arrangements of a fish-counter and inscales.

fish move freely upstream but cannot return. The inscales are essential to divert weeds and debris and to reduce the velocity of the water through the screen unit which is fitted to the upstream end of the inscales. Further protection against weed and descending spent fish is provided by a short extension of the inscales beyond the screen. The screen unit (Fig. 3) consists of vertical nylon monofils of about 0.04 inch diameter, spaced $1\frac{1}{2}$ inches apart, and are held in a vertical frame, each cord being tensioned to about 6 oz. from the top by a light coil spring. The top of the frame is above water and is boxed to house the actuating mechanism. The unit rests in guides affixed to the inscales and can be raised for cleaning. The passage of a fish of width greater than two inches (about 3 lb. weight) displaces the cords sufficiently to operate electrical contacts. Wires from the contacts are connected to the numerical register. The numerical register unit contains a Post Office type subscriber's meter and a time delay. The delay of 1—2 seconds is arranged by means of a capacitor or by a thermal delay. The numerical register can be at a distance from the fish-pass or may be embodied in the counting screen unit.

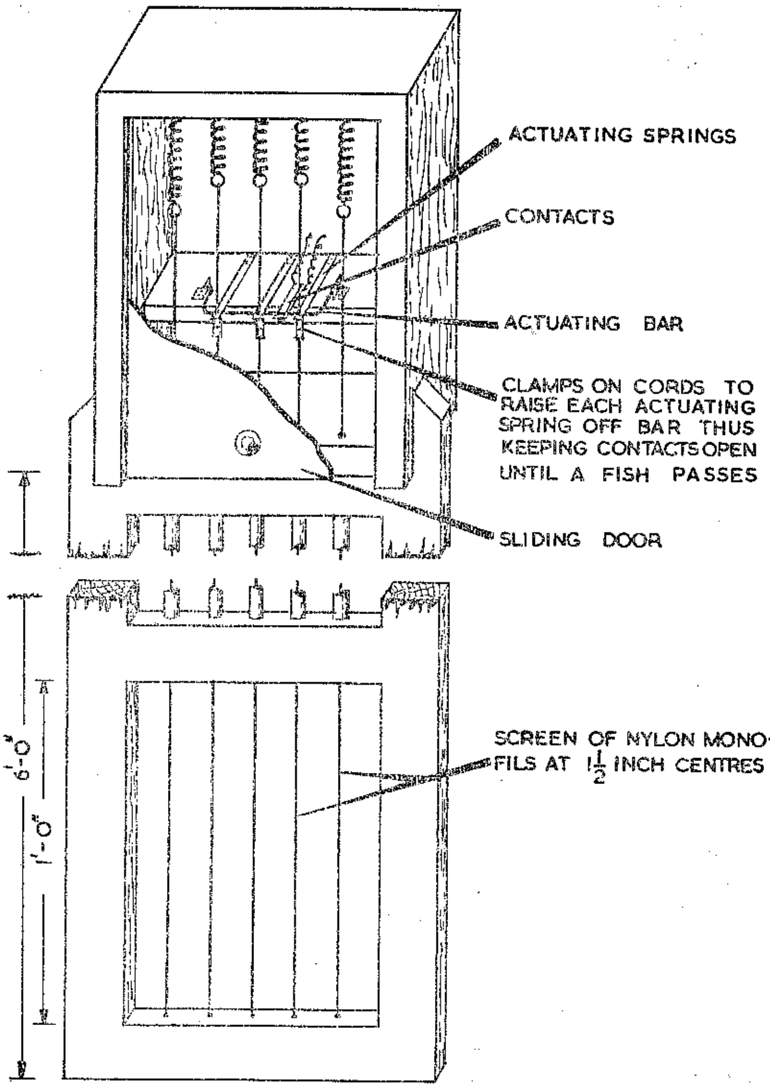

Fig. 3. The fish-counter screen unit. A short (9 inch) projection of the inscales upstream of the screen is not shown in this Figure nor in Fig. 2. (page 4).

A check on the accuracy of this counter was obtained during experiments carried out by an officer of the Fisheries Division, Department of Agriculture and Fisheries. A comparison of the total numbers of fish ascending the pass from 26 June to 8 July 1958 inclusive showed 3,068 fish recorded by the counter at Pool 58 against a (net) visual count of 3,029 fish released from a trap at Pool 24, indicating an error of +1.3% in the counter record. To trace the passage of fish through the fish-pass, counters were placed at each of Pools 10, 24 and 58 and to enable the movements of the fish to be studied in relation to time, standard portable recording voltmeters (chart speed about one inch per hour) were connected to the counters (Fig. 4).

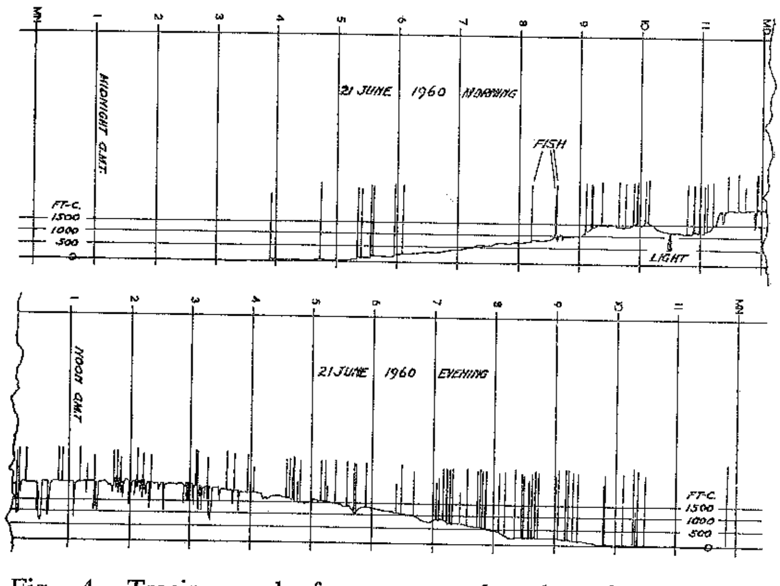

Fig. 4. Tracing made from a recorder chart from the fish-counter at Pool 58 with the photo-cell connected. The height of the trace above the baseline measures the light-intensity. The passage of each fish is recorded as a stroke above the trace.

Light intensities were also recorded by one of the voltmeters by connecting it to a masked 35 mm × 15 mm selenium cell mounted in a glass jar. This gave reliable readings only within the range of 50 to 1,200 ft candles (Fig. 4). The glass jar containing the photo-cell was placed on the side-wall of the fish-pass with the cell horizontal and at about 4 ft 6 ins above the water. The friction of the recording pen on the chart caused over-damping during rapid variations of light intensity and to overcome this a small electro-magnet was attached to the recorder case and energised from a bell transformer. The 50 cycle hum produced enough vibration to overcome the frictional lag of the pen. The photo-cell was calibrated against an instrument of known accuracy. A more sensitive instrument was required for the measurement of light intensities at night and along the stretch of fish-pass situated underneath the power station structure. Underwater readings were also required. For these measurements a 67 mm diameter photoelectric cell enclosed in a water-tight perspex box was used in conjunction with a recording microammeter. The range of the instrument was extended by means of a mask which could be quickly fitted into a slide to cover the photo-cell thus reducing its output to roughly 1/10 of the full aperture value. This photo-cell was also calibrated against a light meter of known accuracy. It was found impossible, from the charts recording the light intensity and the passage of fish, to distinguish a very bright but cloudy period from a period of clear sunshine. This difficulty was overcome by the use of a Campbell-Stokes sunshine recorder which was set up by the Meteorological Service (Dublin). Hours of sunshine in decimals of an hour were abstracted from the charts.

During two seasons, water samples were taken from the fish-pass at nominally weekly intervals. The samples were taken by means of a Knudsen frameless reversing water bottle at a depth of three feet. It was considered that the water was thoroughly mixed. The dissolved oxygen content was determined by the Winkler method using a 500 ml. sample.

RESULTS

Passage of fish through the estuary

The study of the migration of the fish through the estuary has been greatly aided by permission to analyse data obtained by the Fisheries Division, Department of Agriculture and Fisheries, in the course of their work on the fish taken by the commercial draft nets in the Erne estuary in 1959 and 1960. In both years fishing was carried out consistently during the last three hours of the ebb tide and for the first four hours of the flood tide both day and night (O'Riordan, private communication). Nevertheless only 16% of the catch in 1959 and 5% of the catch in 1960 were taken between sunset and sunrise. Further analysis of the Department's figures shows that of the fish taken by the nets, 71% in the 1959 season and 85% in the 1960 season were caught within two hours before and after (but mainly after) low tide. Of the total season's catch, 76% in 1959 and 87% in 1960 were taken on the flood-tide.

It might be argued that large numbers of fish may have escaped the nets at night and during the hours before and after high tide when there was no fishing. However, it can be shown that the nets take a very high proportion of the total run on a fishing day, as follows:

Number of fish entering fish-pass 1 June—16 July, 1959 (46 days)	881
Number of fish taken by nets 1 June—16 July, 1959 (28 fishing days)	573 or 20.5 fish per fishing day
∴ approximate total number of fish entering estuary 1 June—16 July, 1959 (46 days) [1]	1454 or 31.6 fish per day

Thus the nets took 65% of the fish passing through the estuary on an average fishing day. A similar calculation for the period 29 June—26 July, 1960 shows that the nets took 61% of the run of fish on a fishing day. In view of the inefficiency of the manner of fishing which is ensured by the fishery by-laws, the escape from the nets (35—39%) is probably due to the manner of fishing and not to considerable numbers of fish entering the estuary at night and at times other than low tide and not being caught. This being so, we have assumed that the numbers of fish taken by the nets at any time are representative of the numbers of fish then passing through the estuary.

[1] Immediately after this period netting ceased because of scarcity of fish. No fish enter the Abbey River at this time of year and the results of a tagging experiment have suggested that only a small proportion of fish which enter the Erne estuary subsequently enter other rivers (Twomey, private communication). This figure is therefore a fair approximation of the total number of Erne fish in the estuary during the period.

The small catches on the ebb tide indicate that in general the fish run straight through the fishing zone (Fig. 1) with the flood tide to the sanctuary above the fishing zone or to the tailrace and remain there. However, a small number of fish may drop back with the ebb as suggested by Menzies (private communication). The draft nets that fish all stages of the tide operate near the upper limit of the fishing zone. During 1960 these nets took as much as 40% of their catch on the ebb tide but this was only 12.5% of the total fish netted in the estuary during the season.

It has been shown that the run into the estuary in any one day is related to low tide, particularly the beginning of the flood tide, except when low tide occurs during the hours of darkness. When a further analysis of the data is made by summating hour by hour the numbers of fish taken by the netsmen for the whole season, the figures disclose a pronounced peak at about 4.0 p.m. G.M.T. in 1959, and about 6.0 p.m. in 1960 in the numbers of fish netted (Fig. 5). These times coincide very approximately with low water at Ballyshannon Bar during neap tides.

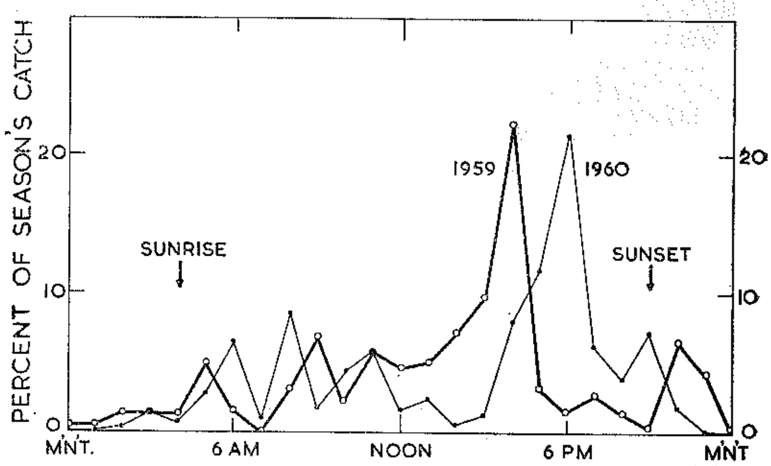

Fig. 5. The total catch by the nets for each of the seasons 1959 and 1960 summated in hours of the day.

The numbers of fish reaching the fish-pass increase at the week-end due to the compulsory cessation of netting at that time. This provides an opportunity to test whether, having run through the estuary on a flood tide, the fish continue through the tailrace to the power station on the same tide. For periods when water conditions were normal in four seasons, the numbers of fish migrating through the lower part of the pass were summated in days-of-the-week for each season. In three years the records from the counter at Pool 24 have been used, but in 1959 the records were taken at Pool 10, closer to the fish-pass entrance. A peak (Fig. 6) in the weekly run through the counter occurred two days after the cessation of netting except in one year (1956) when the interval was only one day. The time taken by the fish to travel from the fish-pass entrance to Pool 24 (see below) has little effect on the results. Close inspection of the power station records shows that during the periods selected there was no apparent difference at week-ends from the normal weekday operation of the power station. It appears then, that the fish do not run through the estuary and tailrace to the fish-pass on the same tide but remain about two days at liberty. As there is no evidence that large numbers of fish drop back down the estuary, it must be

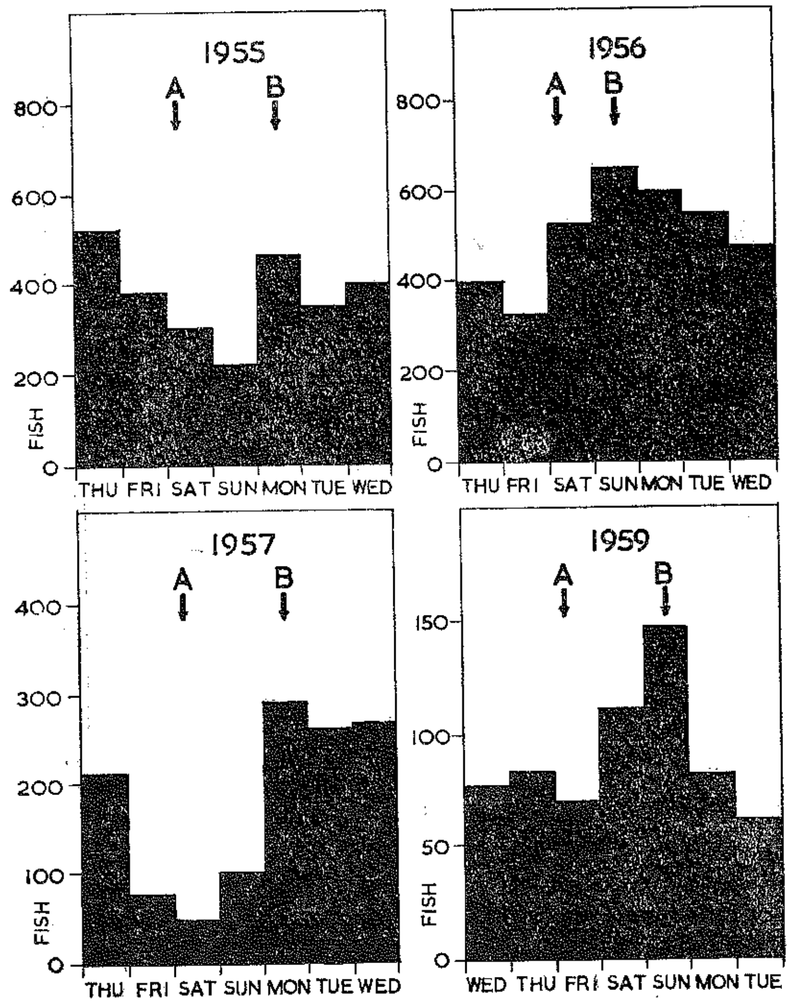

Fig. 6. Numbers of fish entering the fish-pass summated in days of the week for 4 seasons. A peak (B) in the run follows 1—2 days after the cessation of fishing (A) which occurs in the estuary at week-ends.

assumed that at this time they lie mainly in the sanctuary above the fishing zone or in the tailrace. An indication that the majority of the fish do not delay long in the estuary is provided by the almost simultaneous fall in the estuary catch and in the run into the fish-pass at the end of the main run in 1960.

Entry of fish into the fish-pass

In view of the marked connection between the beginning of the flood tide and the main daily migration through the estuary, an examination was made of the hourly count at Pool 10 in relation to the state of the tide to determine whether this connection continued into the fish-pass. The records for July, 1959, were selected because in that month the tidal variations were not masked by heavy discharges from the turbines. During the fishing season in 1959 the power station ran generally for prolonged periods at low loads ("cover running"). These periods were apparently at random over the 24 hours. No connection could be found between any stage of the diurnal tidal cycle and the summated hourly migration at Pool 10. On the ebb, 329 fish were counted and 348 on the flood. However, the numbers of fish entering the pass daily do show a gradual and slight increase after springs through neaps to just before springs (Fig. 7). 45% enter the pass in the period between springs and neaps and 55% between neaps and springs. When allowance is made for the "days at liberty" in the sanctuary or tailrace it would appear that this increase between neaps and springs merely reflects the larger numbers of fish entering the estuary at or near neaps.

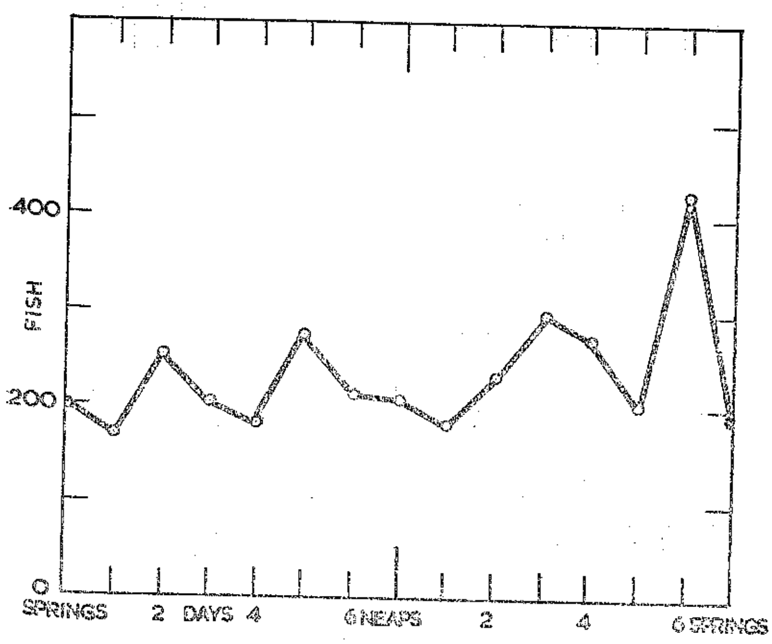

Fig. 7. The summated daily migration into the fish-pass (recorded at Pool 10) for 6 weeks in May-June, 1960, showing a slight increase through neaps to springs.

Finally, a summation of the hourly records of the passage of fish through Pool 10 has also been made in relation to the time of day in two seasons (Fig. 8). From this Figure it can be seen that there is a tendency for a greater number of fish to enter the fish-pass in the evening, and for the run to cease for a period at night. It is worth noting that this tendency to enter the pass in the evening was more pronounced in 1959 which was a dry season.

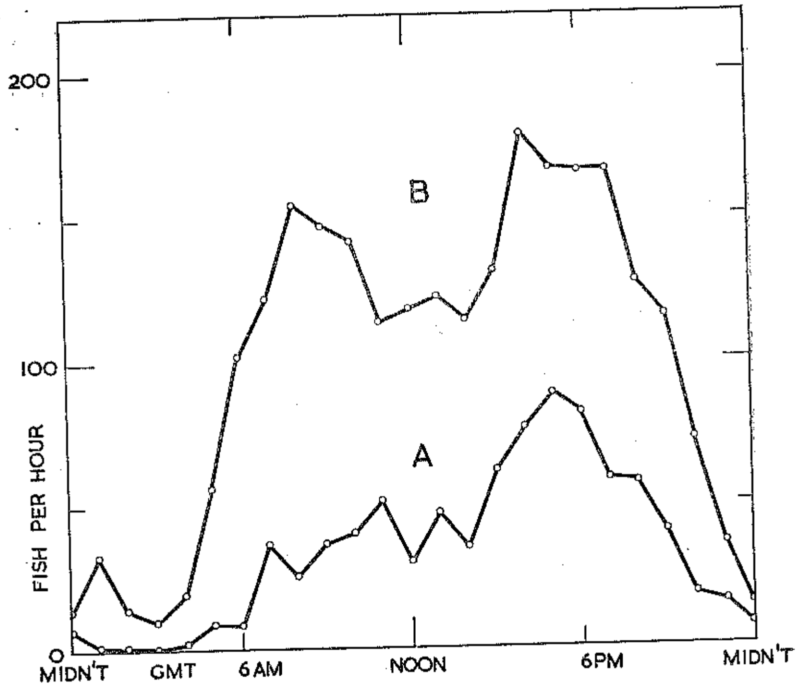

Fig. 8. Migration into the fish-pass summated hourly. A, 28 June—14 August, 1959, and B, 18 June—1 August, 1960.

Passage through the fish ladder

The fish do not enter the fish-pass uniformly throughout the day and this allows the passage of a " peak " to be traced through the three counters and hence the normal rate of movement of the fish can be calculated. This is most clearly illustrated by an occasion on which a run of fish entered the fish-pass in the morning (Fig. 9). This run can be followed through the three counters in one day and shows an interval of some three hours between the beginning of the run at Pool 10 and its arrival at Pool 24, and about a further five hours between Pool 24 and Pool 58. By extrapolation, the normal interval between the time a fish enters the pass and the time of its arrival at Pool 10 is about $1\frac{1}{2}$ hours. Similarly, the time to reach the top of the fish-pass from Pool 58 is about $2\frac{1}{2}$ hours. This indicates that the time taken by a fish to ascend the fish-pass in daylight is about 12 hours. Fig. 10 shows a similar pattern of movement in a run which also entered the fish-pass in the morning. A run of fish which entered the pass in the evening can also be traced through the three counters. Not all the fish in this evening run at Pool 10 had passed through Pool 24 before the night-time cessation of movement. The fish which had not passed through Pool 24 by nightfall continued their migration after dawn. Allowing four to five hours of darkness during which there was little activity, it is clear that the actual number of daylight hours taken to travel between Pool 24 and 58 was not much greater than when the fish ascended within a single day. Some records which were incidental to experiments carried out by an officer of the Fisheries Division,

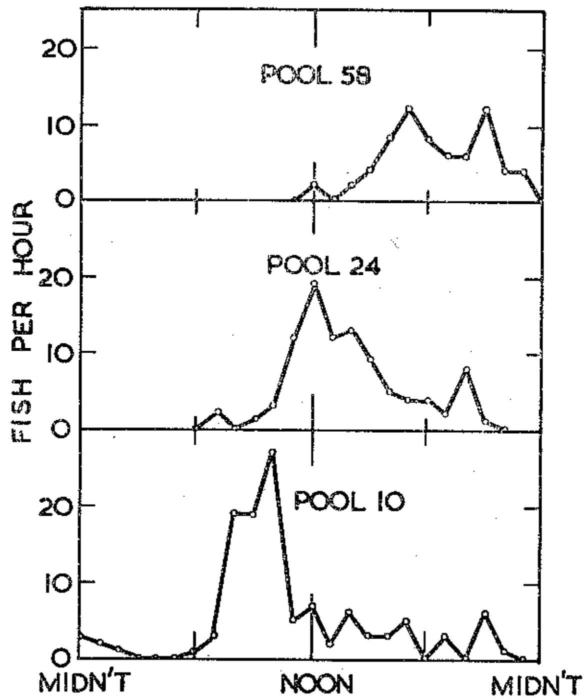

Fig. 9. The numbers of fish passing each hour through the three counters in the fish-pass, 16 June, 1960.

Department of Agriculture and Fisheries, provide an opportunity to make another estimate of the travelling time between Pool 24 and Pool 58. In this experiment the fish were released periodically from Pool 24 and were counted at Pool 58. The average time observed by this method was 4.1 hours as compared to the estimate (above) of 5 hours (Table 1).

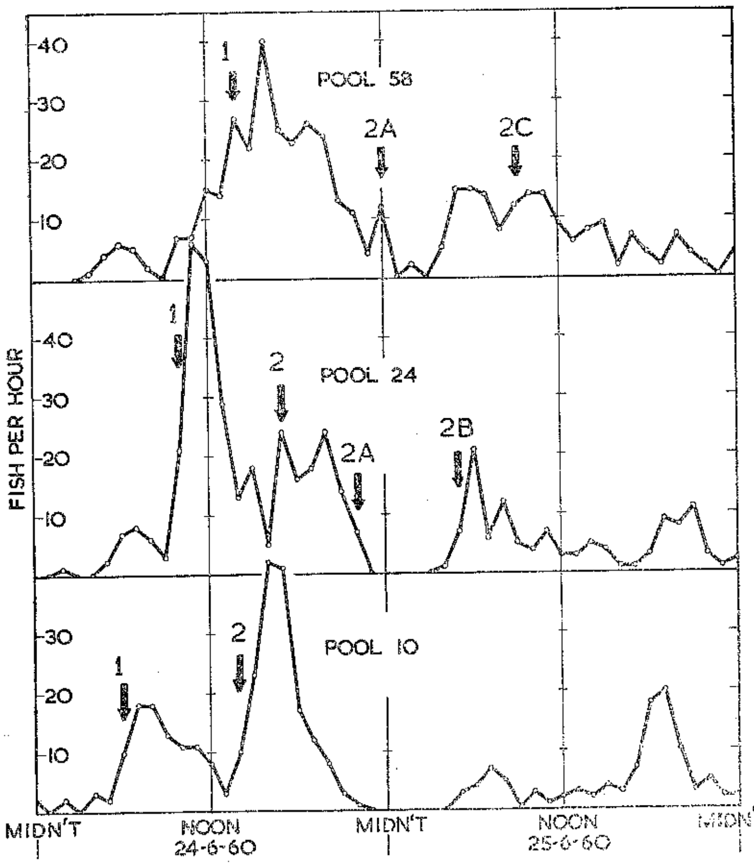

Fig. 10. A morning run (1) and an evening run (2) at Pool 10, followed through Pools 24 and 58. The evening run had not all passed through Pools 24 and 58 when movement ceased at nightfall (2A). The run at Pool 24 was resumed after dawn (2B) and passed through Pool 58 before noon (2C).

TABLE 1

RATE OF PASSAGE OF FISH BETWEEN POOLS 24 AND 58

Date	Time of release from Pool 24	Time of arrival of "Peak" at Pool 58	Time taken
27.6.58	Hour ending 10 a.m.	Hour ending 2 p.m.	4 hours
28.6.58	„ „ 10 a.m.	„ „ 2 p.m.	4 „
30.6.58	„ „ 9 a.m.	„ „ 1 p.m.	4 „
30.6.58	„ „ 5 p.m.	„ „ 8 p.m.	3 „
1.7.58	„ „ 9 a.m.	„ „ 2 p.m.	5 „
2.7.58	„ „ 8 a.m.	„ „ noon	4 „
3.7.58	„ „ 10 a.m.	„ „ 2 p.m.	4 „
4.7.58	„ „ 9 a.m.	„ „ 1 p.m.	4 „
8.7.58	„ „ 10 a.m.	„ „ 3 p.m.	5 „
8.7.58	„ „ 5 p.m.	„ „ 9 p.m.	4 „

Average time taken = 4.1 hours.

Light and the passage of fish

It has been shown (Fig. 5) that the migration of salmon into the estuary almost ceases at night, at least during the months of June, July and August. As daylight fails, the migration in the fish-pass also diminishes and there is little activity during the hours of darkness (Fig. 8). Exceptions do occur. There have been some considerable runs during the night. One such occasion was 30 June/1 July, 1958, when a run at Pool 58 commenced at 7.0 p.m. G.M.T. and continued until about 8.0 a.m. the following morning. 324 fish were recorded, including about 100 during the hours of darkness. The numbers counted before and after this run were comparatively few. The normal regime at night in the pass is illustrated by the runs in different months (Fig. 11). Examination of this data indicates that although the total is small, a greater proportion of the fish travel at night in September, October and November than in the preceding months.

The daily migration through Pool 58 commenced at dawn in all the months studied and fell off with the failing evening light. However, in September to November, the "tail" of the daily run continues for some hours after nightfall. Although sunset advances from about 9.0 p.m. in June to about 5.0 p.m. in November, the "tail-off' in the numbers of fish changed only from the period 6.0 p.m.—11.0 p.m. in June to 6.0 p.m.—9.0 p.m. in November. It is improbable that the lights in the power station buildings and grounds stimulate the continued migration after nightfall. These lights remain switched on from dusk to dawn throughout the year. The night-time light intensity measured just above the water surface at Pool 58 was between 0.1 and 0.2 ft-candles.

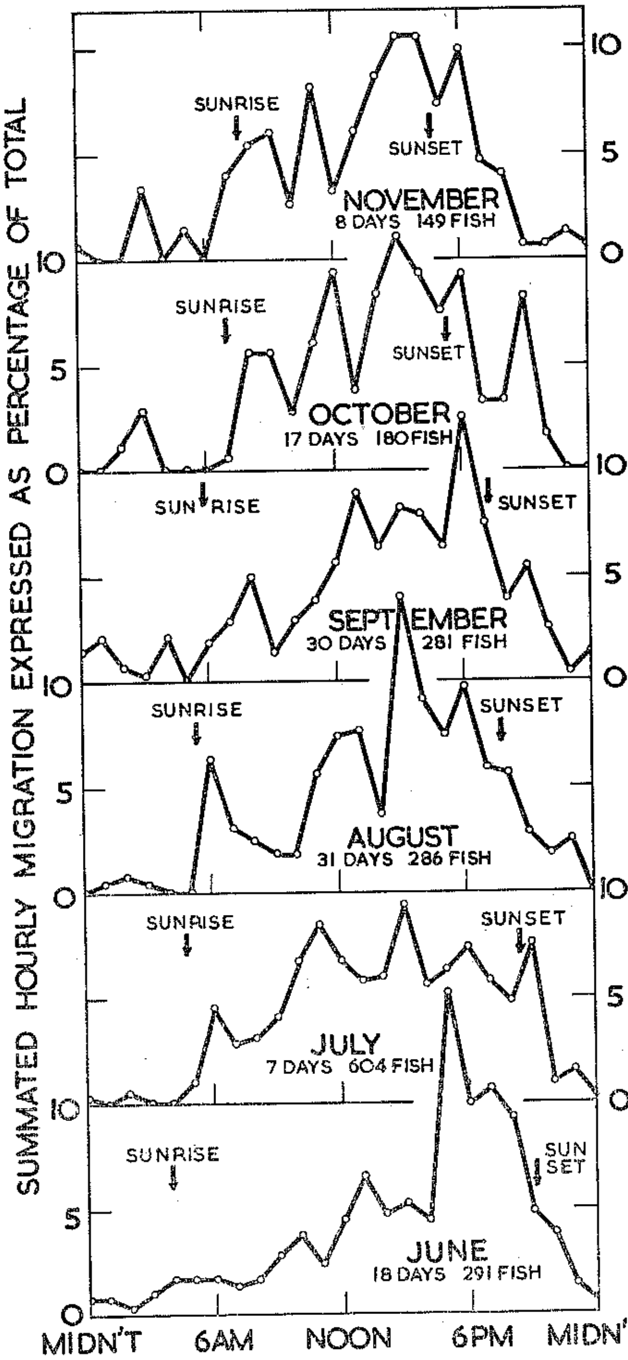

Fig. 11. The summated hourly migration through Pool 58 for each month June—November, 1958. The period of daily activity remained fairly constant during this time.

In view of the cessation of migration during the hours of darkness both in the estuary and fish-pass, it was thought that artificial lighting of the lower portion of the fish-pass at night might yield results relating to the significance of light in the movement of fish. This part of the fish-pass is under the power station structure and is largely shaded from direct daylight. Four 200 watt floodlights were mounted to illuminate the pass from the entrance up to the counter at Pool 10. With the exception of the light illuminating the counter, the floodlights were placed facing downstream. The floodlight in the entrance-chamber gave a light intensity of 2.75ft-c. at mean water level and also illuminated the entrance slot. This value is higher than the estimated light intensity at the time of entry of the first morning fish.

For the first experiment the floodlights were switched on and off on alternate nights for a period of nearly two weeks. The hourly counts of fish at Pool 10 were summated for each condition

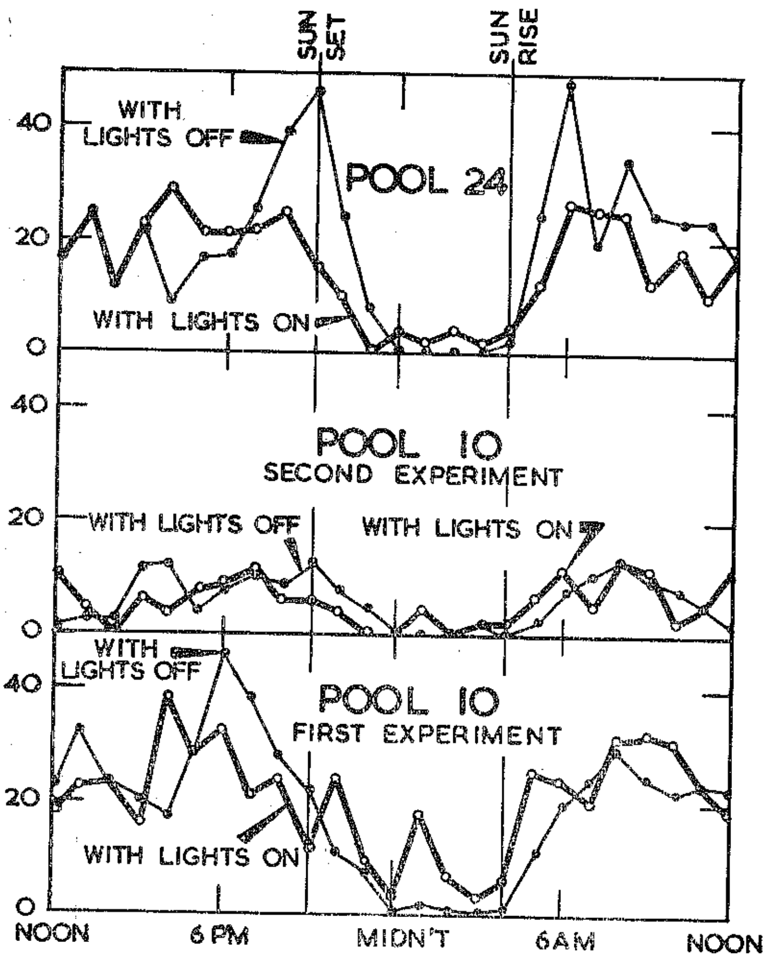

Fig. 12. The effect of illuminating the lower part of the fish-pass at night upon numbers of fish passing through Pools 10 and 24.

(Fig. 12) and a comparison made of the percentage which passed through during the hours when fish are not normally recorded at Pool 10, i.e., between 11.0 p.m. and 4.0 a.m. G.M.T. Four of a total of 459 fish (0.9%) were counted in the six " lights off" nights, but in the six " lights on" nights 38 of a total of 500 fish (7.6%) were recorded. For the second experiment the floodlight at Pool 9 was removed and re-erected to illuminate the area of the tailbay near the entrance to the fish-pass. The results were summated as before. Two fish in a total of 137 (1.5%) were counted in the " lights off" nights and 8 fish in a total of 137 (6.1%) in the " lights on" nights (records for four nights under each condition). As the second experiment differed from the first only in the re-siting of one floodlight, they were considered together for statistical analysis using Student's " t" test. The increase in the migration at night through Pool 10 on the " lights on" nights is probably significant ($P = < 0.05$).

The question has been raised by Menzies (private communication) as to whether the fish which were stimulated by the light would stop in the dark pools immediately above Pool 10 or move on. The hourly records from the counter at Pool 24 for a period of three days during the first experiment were also summated. They show a run at night of two fish in 448 (0.4%) with lights off and 17 fish in 360 (4.7%) with lights on.

Short periods of bright sunshine may inhibit the movement of fish but this is not very pronounced, particularly in the morning and evening (Fig. 13). A bright but clouded sky, giving a light

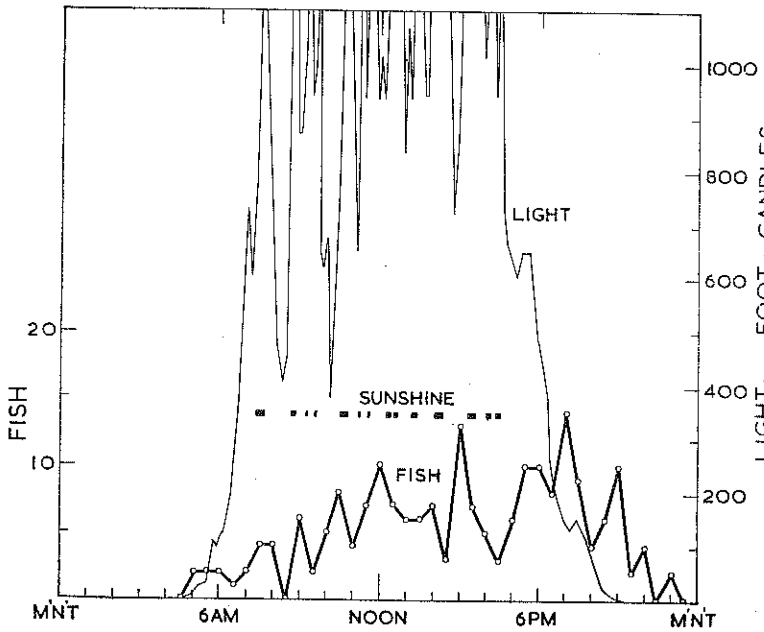

Fig. 13. The half-hourly migration through Pool 58 on 30 July, 1958, related to light-intensity and periods of sunshine.

intensity of 2,000 ft-candles or more, may also have an inhibiting effect. At Cathaleen's Fall long periods of sunshine do not appear to halt the migration in the manner described by Ward (1939). From direct observation (through a window in the fish-pass) it appears that salmon resting in the ladder do not seek shade from the sun.

Effects of other environmental conditions

Examination of daily and hourly rainfall records from 1955 to 1960 inclusive reveals no *direct* connection between rainfall and the daily migration of fish except on one occasion (13 August, 1959) when following a drought, widespread heavy rain (0.7 inch) gave rise to the movement of a small number of fish through Pool 58, but it induced no run of fish into the pass. In five other cases when increased migration followed heavy rain, it was noted that the increase followed some days after the rain and could be more correctly related to changes in the river-water such as would occur with a natural spate (see below).

The water temperature in the fish-pass at Cathaleen's Fall was taken daily for 6 years. In each year it had risen to 5.5°C before the run began, i.e., the lowest temperature at which salmon will ascend the Pitlochry fish-pass (Pyefinch, 1955). The numbers of fish arriving at or leaving Cathaleen's Fall when water temperatures are low are not sufficient for us to be sure that the fish-pass does not present some obstacle to the fish at low temperatures. Nevertheless, it is certain that 5.5°C does not represent a threshold temperature below which the fish are *unable* to ascend the Cathaleen's Fall fish-pass. Prior to 20 March, 1954 (before the water temperature rose to 5.5°C) 12 fish were recorded. In December, 1958, as the residue of the summer's standing population moved out of the fish-pass, 36 fish were recorded at Pool 58 with a water temperature of 4.5°C. Differences greater than 1°C in the water temperature of the fish-pass from day to day are unusual. Because the temperature readings were taken at the same time each morning it was felt that they might not represent the full diurnal variation. Accordingly, for a period of more than a month, maximum and minimum temperatures were taken daily in the fish-pass. The greatest variation recorded in any one day was only 2°C. No changes in the numbers of fish migrating through the fish-pass could be attributed to these variations in temperature. We have no evidence, either, that high water temperatures inhibit migration in the Erne. Some good runs of fish occurred with a water temperature of 20°C.

The wide variations in flow which occur in the tailrace from hour to hour, dependent upon power station operation, are equivalent to artificial freshets. We have not been able to trace any effect on the run of salmon (within a single day) from these short-term fluctuations. However, prolonged high discharges from the turbines, such as occur during a flood, have a considerable effect on the run. In July, 1955, sustained flows of 80—150 cubic metres per second were accompanied by a marked reduction in the numbers of salmon migrating and recorded at Pool 24 (Fig. 14)

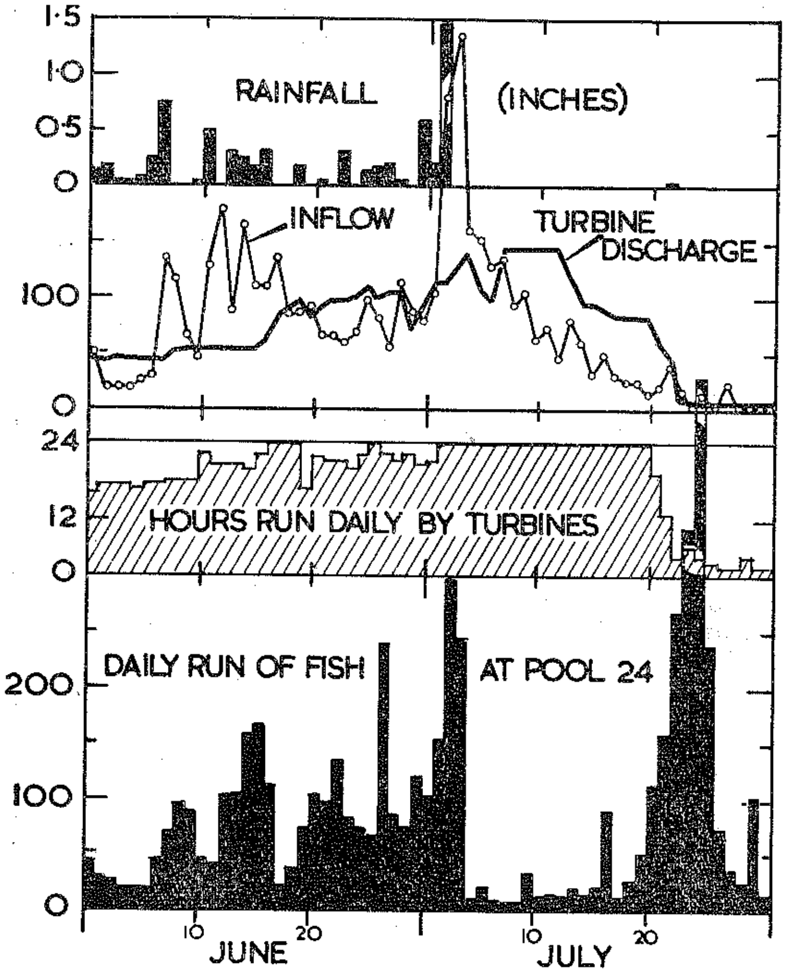

Fig. 14. The daily migration through Pool 24, June and July, 1955, related to rainfall, inflow to the river, turbine discharge (cubic metres per second) and the hours run daily by the turbines.

In 1955, 1958 and 1960 there were in all six such periods of reduced migration which can be attributed to continuous heavy flows. In each case a recovery of numbers of fish migrating followed the return to intermittent operation of the turbines. In two instances the sustained high flows lasted for more than a week and were followed by peaks in the run of fish. When heavy rain produced a considerable rise in the inflow to the river system—such as would have caused a spate before the construction of the power stations—this was followed after an interval of some days by larger runs of fish. Six instances are to be found in the records for 1955, 1958, 1959 and 1960. During the same period there was only one case when a comparable rise in inflow to the river was not followed by an increase in the numbers of fish migrating. The length of the interval between rising inflows and the increase in the numbers of migrating fish appears to depend on the average discharge from the power station at the time. In a dry season (1959) when the average discharge was about 17 cubic metres per second, there was an interval of 4 days between the rise in inflow and the increase in numbers. In 1955, which was a wet season, the average discharge was about 100 cubic metres per second and the interval was only one day. The sequence of events (in 1955) can be followed in Fig. 14. Heavy rainfall on 7 June caused a sharp rise in the inflow to the river on the same day, and was followed on 7—10 June by an increase in the daily count of fish. Further rain maintained the inflows for 10 days and there was a good run of fish from 13 June to 17 June. Thereafter, the numbers dropped greatly during a period when the turbines ran continuously for three days. The migration was resumed when the continuous discharge ceased. Continuous running again on 26 June was followed on 27 June by a good run. Rain, heavy on 30 June and very heavy on 2 July, brought very high inflows on 2—3 July which were again followed on 3 July and 4 July by good runs of fish. A period of continuous high discharge starting on 3 July, lasted until 20 July and coincided with a marked reduction in migration which recovered on 21 July and showed a peak of 480 fish on 25 July. A similar but less marked reduction in the rate of migration accompanied a continuous discharge from 17 to 24 July, 1958 (Fig. 15).

Other aspects of the behaviour of salmon in the fish-pass

Differences in the daily count recorded by the three counters show that a standing population of fish develops from time to time in the fish-pass. This appears to be independent of the numbers of fish migrating. It may build up and disperse several times in the course of a season. In 1958, a year when commercial fishing was suspended, the standing population in the fish-pass increased gradually between 7 and 17 June (Fig. 15). It remained fairly steady until 24 June and then dispersed gradually towards the end of the month. The numbers increased again during the first week of July and declined sharply between 29 July and 1 August. The growth and decline are usually gradual but not invariably so, and a cycle may cover a week or several months. The standing population in the fish-pass between Pools 24 and 58 may exceed 300 fish. There is no obvious connection between the growth of a standing population and changes in those environmental conditions for which records are available. A *decline* in the standing population can be associated with increased inflows to the river system in 14 of the 16 instances recorded, e.g., 25 June and 26—28 July (Fig. 15), and in one instance with heavy rainfall which yielded no apparent increase in inflows. There were, however, 15 comparable increases in inflow which had no apparent effect on the standing population. Increases in inflow are followed by increases in the dissolved oxygen content of the water in the fish-pass at Cathaleen's Fall (Fig. 15). Our data relates only to changes in dissolved oxygen at weekly intervals. Daily readings would have been required to assess the full extent of the increase in oxygen content associated with increased inflows.

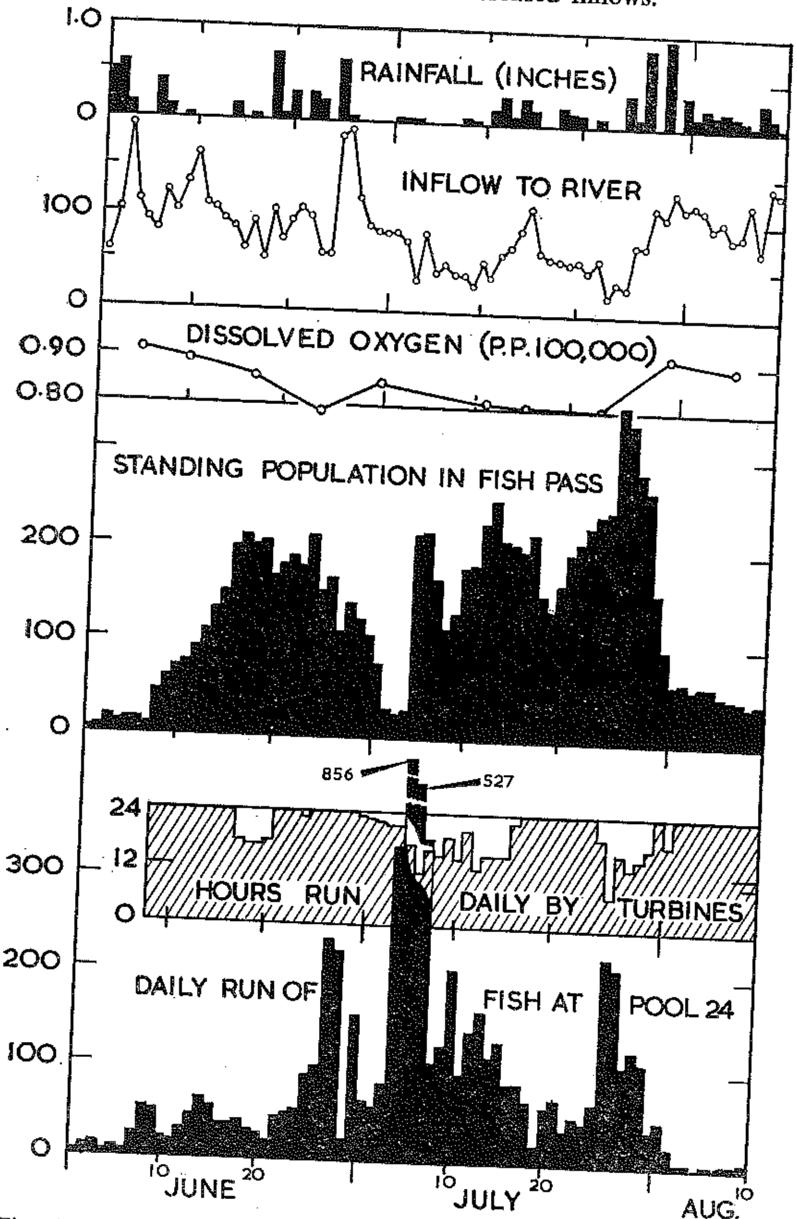

Fig. 15. The standing population of salmon in the fish-pass June—August, 1958, related to rainfall, inflow to the river (cubic metres per second), dissolved oxygen in the water of the fish-pass, hours run daily by the turbines and the migration through Pool 24.

The graphic records indicate a tendency for the fish to go through the counters in shoals (Fig. 4) although it was sometimes difficult to differentiate between groups and single fish on the recorder charts, especially during a heavy run. Because of this difficulty, the following rules were adopted for reading the charts and assessing the frequency of 'Single Fish', 'Twos', and 'Shoals'.

(1) Days were excluded on which the run was more than 100 fish.

(2) Days were excluded on which the free passage of fish was interrupted.

(3) One fish, recorded with an interval of at least 10 minutes before and after, was regarded as a 'Single Fish'.

(4) Two fish recorded within 10 minutes but with three times the interval between these two fish elapsing between them and those preceding or succeeding them, were regarded as Twos'.

(5) 'Shoals'—as for 'Twos' (less than 10 minutes between members) but with an interval before and after of more than three times the mean interval between members of the group or shoal (three or more fish).

After application of these rules to the graphic records from the counter at Pool 58 for one year, it was found that of the 1,770 fish that remained after applying Rule 1, single fish made up 30%, 'Twos' 39% and 'Shoals' 31% (Table 2).

TABLE 2

SHOALING IN THE FISH-PASS

Period	Single fish %	Twos %	Shoals %	No. of fish
June (1-14)	34	54	12	205
July (22-26)	30	28	42	227
August	30	39	31	286
September	41	29	30	281
October	23	45	32	589
Nov. (1-14)	27	37	36	182
Mean—June/Nov.	30	39	31	1770
		70 %		

DISCUSSION

It is clear that the salmon do not enter or pass through the estuary of the Erne in a random manner. The main run of fish occurs in daylight around the time of low tide. The fish show a particular preference for running with the first two hours of the flood tide. Taking the season as a whole, larger numbers of fish enter the estuary at about 4 to 6 p.m. G.M.T. This may indicate a preference for entering the estuary at low water of neap tides which occurs at this time of day, or that some additional stimulus is provided by the evening light. These observations correspond with those of Hayes (1953) who states that the conditions just mentioned are likely to favour migration into an estuary.

The fish, having entered the estuary, do not run through to the tailrace and the fish-pass on one tide but under normal conditions they remain some two days in the estuary. Presumably the majority of fish spend this period in the sanctuary above the fishing zone or in the tailrace as only a small number drop back to the nets on the ebb tide.

Although the passage of fish through the estuary appears closely associated with the diurnal tidal cycle, this is not reflected in the numbers of fish per hour entering the fish-pass. The daily migration of fish into the fish-pass does show a slight increase after spring tides through neaps to just before springs and this appears to be a reflection of the increased numbers of fish available in the estuary at neaps.

The possible importance of the intensity, angle or direction of the light in the evening in attracting larger numbers of fish into the estuary (coinciding with neap tides) and fish-pass is suggested by the marked influence of light upon the regime in the fish-pass itself. The most striking feature of the entry and passage of the salmon through the fish-pass is the almost complete cessation of movement at night. Flood-lighting the lower portion of the fish-pass on 10 alternate nights induced a small but statistically significant increase in the numbers of fish recorded during the hours when movement is minimal, i.e., between 11.0 p.m. and 4.0 a.m. G.M.T. Despite the fact that the fish-pass was not illuminated above Pool 10, the runs of fish through Pool 24 also showed a small increase on the " lights on " nights. It would appear that the small run of fish induced by the flood-lights continued to a decreasing extent through the unlighted part of the pass and even at Pool 24 was not fully expended. Recently Pinhorn and Andrews (1963, 1965) have investigated the behaviour of juvenile Atlantic salmon in response to light stimuli and in light gradients after adaptation to fixed photo-periods. The fish showed consistent negative photo-tactic responses except that there was some reversal of this behaviour at the lowest light intensities, e.g., the fry showed positive phototactic behaviour when exposed to light stimuli at intensities of the order of 0.1—0.2 ft-c. Unfortunately there is no experimental data on the behaviour and retinal responses of adult Atlantic salmon in relation to various light intensities. It is likely that adult and young salmon will differ in these respects. Nevertheless, a consistent feature of the work on young Pacific salmon is a change in behaviour and visual capabilities at levels of illumination around those at which the retina changes from light adapted to dark adapted and *vice versa* (see Brett and Groot, 1963, for a review). Ali and Hoar (1959) have shown that retina of fry of the pink salmon, *O. gorbuscha*, is incompletely light or dark adapted at illuminations between 0.1 and 1.0 ft-c. The light intensity at the surface of the Cathaleen's Fall fish-pass at night when the migration of adult salmon ceases is of the order of 0.1—0.2 ft-c. The illumination created by the flood-lights in the experiment referred to above, and by natural illumination when the first fish enters the pass in the morning, is above 1.0 ft-c. which is the light intensity at which the retina of pink salmon fry becomes fully light adapted.

In the fish-pass the fish exhibit a more or less fixed period of daily activity which in June and July is about eighteen hours, contracting to about fourteen hours in November. The start of daily activity appears to be linked to dawn, but the nightly cessation of movement does not appear to be linked so closely to dusk. In October and November the fish continue to run through the upper pools of the pass for several hours after nightfall, although migration ceases shortly after dusk in June and July. MacKinnon and Brett (1953) record that fish continue to move out of the top pool of the Stamp Falls fish ladder during the first $1\frac{1}{2}$ hours of darkness in September and October. These observations, plus the evidence provided by the flood-lighting experiment, suggest that once movement is stimulated during daylight it is not immediately inhibited by darkness. The eventual cessation of movement at night in the fish-pass and in the estuary is in contrast with behaviour in coastal waters where, according to Went (private communication), migration takes place both night and day.

It has not been possible to establish a relationship between actual light intensities and the rate of migration of the salmon through the fish-pass on the Erne similar to that obtained by MacKinnon and Brett (1953) for the La Have River. Ward (1939) reports a slackening in the run of fish during the middle of the day even in cloudy weather but more especially in sunshine. On the Erne, reductions in the rate of migration may be associated with *short* periods of sunshine and also, perhaps, with very bright but cloudy skies when the light intensity exceeds about 2,000 ft-candles. The variable nature of the run of fish through the pass makes it difficult to detect any reduction in migration which might be associated with long periods of sunshine.

We have estimated that a fish can traverse the entire length of the fish-pass in about 12 hours. However, because of the cessation of movement at night, coupled with the preference shown by the fish to enter the pass in the evening, the passage of the majority of the fish is as follows. They enter the fish-pass in the evening and spend one night in it; some passing through Pool 24 and some failing to do so before nightfall. They complete their journey through the pass to enter the reservoir in the course of the following day. Again some preference is shown for migration through the upper pools of the pass in the evening. The fact that numbers of fish remain overnight in the Cathaleen's Fall fish-pass is in contrast with the observation of MacKinnon and Brett (1953) that the Stamp Falls fish-pass was empty of fish at night. The Stamp Falls pass consists of only 13 steps rising 25 feet compared to the 73 pools with a rise of 112 feet at Cathaleen's Fall. As noted above, the fish continue to move through both passes for some time after dusk and this may be sufficient to clear the Stamp Falls pass of fish at night because of its shorter length.

MacKinnon and Brett (1953) were unable to relate any change in the rate of migration of salmon to small fluctuations in temperature. Hayes (1953) also found that temperature has little effect on the run of fish. Similarly, at Cathaleen's Fall no fluctuations in the rate of migration through the fish-pass could be related to changes in water temperature between 2°C and 20°C. No indications have been found on the Erne of a threshold temperature below which the fish will not ascend the fish-pass as recorded at Pitlochry by Pyefinch (1955). However, the numbers of fish entering the Erne in winter and spring when the temperatures are low are too few to enable absolute conclusions to be reached.

Although the normal, intermittent, running of the power station gives rise to artificial freshets which, according to Hayes (1953), might be expected to induce the salmon to leave the estuary for fresh water, there is no evidence that the intermittent running has such an effect in the Erne. Heavy rainfall in the Erne catchment is usually followed by a spate, and then in the course of water regulation, by heavier discharges from the power station. Increased runs of fish into the fish-pass have been recorded following heavy rainfall, but only after an interval of one or more days. The length of the interval appears to depend to some extent on the volume of the discharge from the power station following the rain. From this we conclude that, when a run of fish follows heavy rain, the factor which initiates the run is more probably some quality of the spate-water (e.g., higher oxygen tension, see Fig. 15) rather than the rain itself or the increased volume of discharge which follows. Prolonged, continuous high discharges from the power station starting while the fish are running in moderate or large numbers, is accompanied by a marked reduction in the daily migration into the fish-pass. When the turbines return to intermittent running, migration is resumed. Subsequent to a period of continuous operation lasting more than a few days, the number of fish entering the pass rises sharply. On 3 and 4 July, 1955, the beginning of a period of heavy, continuous discharge, there were excellent runs of fish into the fish-pass. It was only after July 4 that there was a marked reduction in the number of fish recorded at the pass. We conclude that fish are able to negotiate the tailrace and enter the fish-pass in flows such as were experienced in July, 1955, and that the run is only delayed by continuous heavy flows. The delay appears to be like that in an unusually swollen river (Ward, 1939).

A high proportion of salmon pass through the fish counters in "pairs" or larger groups, and there is a tendency for a standing population to develop in the fish-pass. This suggests that here, as in the sea (Went, 1955), the salmon tend to shoal. Finally, the onward movement or dispersal of a standing population in the fish-pass is almost invariably associated with an inflow of fresh water following a period of heavy rain. This reinforces the suggestion that inflows of fresh water to the river system with the associated increase in dissolved oxygen can stimulate runs of fish. It has to be admitted, however, that such inflows can occur without disturbing a standing population.

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